October 9, 2020

Comments on Further Notice of Proposed Rulemaking

Mitigation of Orbital Debris in the New Space Age, IB Docket No. 18-313
Submitted by the Picosatellite and Nanosatellite Developers Group

Comments of the Commercial Picosatellite and Nanosatellite Developers Group

The Commercial Picosatellite and Nanosatellite Developers group (CPND) consists of eight organizations developing and promoting high performance picosatellites (PocketQubes) and nanosatellites (1-3U CubeSats). Three of these, Care Weather Technologies, Open Research Institute, Applied Ion Systems, Mini-cubes, and Skyline Celestial are U.S. organizations developing or promoting PocketQube and small CubeSat technologies. The other three organizations, Alba Orbital, Citadel Space Systems, and Fossa Systems, are European companies that provide satellite services to U.S. customers.

Lower costs promote U.S. leadership in innovation by allowing greater diversity of experimentation. Pico- and nano-satellites are the cutting edge of high performance from small, low-cost form factors. Pico- and nano-satellite applications include weather observation (Walton, 2019), machine to machine connectivity (Mohney, 2019), spacecraft inspection (Walton, 2019), and spectrum mapping (Estevez, 2020). PocketQubes, a class of picosatellite, now have a proven record of trackability, with 16,000 TLEs for 10 spacecraft flown as of May, 2020 (Alba Orbital, 2020).

While we are concerned about proposed rules that could cripple the pico- and nanosatellite categories, we support greater stewardship of the orbital environment. We ask that new rules account for the differences between large and small satellite classes. The community developing high-performance pico- and nano-satellites is still in its infancy. It is important to American innovation that orbital debris rules protect the orbital environment without crippling the pico- and nano-satellite communities.

1. In response to point 164, limiting the orbits at which non-maneuverable satellites can operate is extremely costly to the pico- and nano-satellites industry. Requiring maneuverability from pico- and nano-satellites above 400km eliminates nearly all launch opportunities.[1] This painfully constricts innovation of nanotechnologies for satellite applications in the United States.
2. We recommend the commission acknowledge that the presence of maneuverability does not eliminate risk, it only decreases it. Operators regularly adopt some threshold risk of collision for their avoidance maneuvers[2]. Satellites with a potential conjunction are only maneuvered until the probability of collision is reduced below this threshold. Potential conjunctions with initial risk below this threshold are ignored. In Appendix A, we show that, for a 15,000-satellite megaconstelltion, reductions in threshold for allowable post-maneuver probability of collision risk for a single conjunction must be unreasonably high (1.0E-10) to reduce the aggregate probability of a single collision to an acceptable level (0.001).

[1] See, for example, flight opportunities listed by Spaceflight Industries at https://spaceflight.com/schedule-pricing/. Roughly half of flight opportunities are above 400km and nearly all SSO are above 400km.
[2] For example, footnote 566 of the FNPRM gives Telesat's recommendation that maneuverability be used to reduce the probability of collision below 0.001 for each conjunction.

3. There is a dramatic difference between the aggregate probability of collision of large maneuverable constellations and small non-maneuverable constellations. In Appendix B, we find even a very low 1.0E-6 threshold for allowable probability of collision per conjunction leaves a fully-maneuverable megaconstellation 50X more likely to be involved in a collision than a non-maneuverable small constellation. Maneuverability is not an effective measure of the debris risk of a constellation.

4. In response to point 157, given the ineffectiveness of maneuverability as a measure of debris risk, we recommend the commission mitigate orbital debris by placing a cap on the aggregate probability of collision of the constellation. To enforce this cap, we recommend the commission require organizations to re-evaluate probability of collision before each launch. We recommend the commission prohibit organizations that have exceeded the cap from launching additional satellites until they can demonstrate that (1) they have reduced their expected debris below the cap and (2) the additional launch will not exceed it again. To reduce their aggregate probability of collision, organizations can wait for their constellation to drop below the cap as satellites deorbit passively. Or they can actively reduce their aggregate probability of collision by deorbiting old satellites and removing defunct satellites from orbit.

5. By accounting through debris risk using aggregate probability of collision instead of the simple presence of maneuverability, the commission provides for continued innovation in nanotechnology for satellite applications by reducing the barriers for small, non-maneuverable satellite constellations whose aggregate risk is lower than large constellations with maneuverability.

6. Our proposed cap on aggregate probability of collision provides the incentive for shortened times on orbit requested by the commission in point 169, because the number of lifetime conjunctions is proportional to time on orbit.

7. To continue to support innovation, in response to point 204, we recommend that satellite applications with very low aggregate probability of collision be exempt from bond requirements. Total project budgets for the smallest of these innovative missions are near the level of the proposed minimum bond, such that the minimum bond would make these missions unaffordable. This would be a costly hit to American innovation in nanotechnology for space applications.

Members of The Picosatellite and Nanosatellite Developers Group

Descriptions of the member organizations of the Picosatellite and Nanosatellite Developers group are listed below.

Care Weather Technologies

www.careweather.com

Care Weather Technologies is a United States weather satellite developer, working to meet the needs of the U.S. science and forecasting communities for more frequent mappings of wind over the surface of the ocean. Our satellite constellation will measure wind over the surface of the entire ocean every hour, where the current rate is a couple times per day. These observations are critical for improving the accuracy of large-scale storm forecasts, especially hurricanes. Traditionally the rate of these observations have been limited by the ~$100M cost of developing and launching the satellites that collect the measurements. We are miniaturizing these satellites, called scatterometers, into a CubeSat form-factor. This reduces launch cost to the point where it is feasible for us to maintain the 80-satellite constellation required to measure global ocean winds hourly. We are developing ground-breaking measurements that are critical to national safety and security, but this leaves us with tight budgets for satellite cost, volume, and power consumption. We request the FCC consider our responses to the proposed debris mitigation rules to balance the need for orbital safety with the need to provide more accurate weather prediction to the American public.

Open Research Institute

Open Research Institute, Inc. (ORI) is a non-profit 501(c)(3) research and development organization which provides all of its work to the general public under the principles of Open Source and Open Access to Research. One important purpose of ORI is to facilitate worldwide collaboration in the development of technology that would otherwise be restricted under United States national laws like ITAR and EAR. By making use of carve-outs in ITAR and EAR for published knowledge, we can share this work with the public worldwide. We have successful, active, and ongoing legal and policy efforts in this area that promote and protect public domain amateur communications satellite work.

Applied Ion Systems

www.appliedionsystems.com

Applied Ion Systems (AIS) is a United States startup working on the open development of ultra-low cost electric propulsion (EP) systems for nanosatellites. Currently, AIS is focusing on EP technologies specifically catered to nanosatellites in the Cubesat and PocketQube classes. To date, there are no propulsion solutions on the market yet for PocketQube class satellites, and most Cubesat teams are unable to afford propulsion that is available. AIS aims to lower the barrier of entry through transparent development of EP systems, closely engaging the nanosatellite community, and providing low-cost and simplified propulsion that meets the demands of the majority of teams that cannot currently access available thruster technology. AIS has two pulsed plasma thrusters aboard the AMSAT-Spain GENESIS N and L PocketQubes, and is working on a new generation of ion electrospray thrusters for nanosatellites. As one of the only active propulsion developers for PocketQube EP, AIS feels that propulsion is still in very early stages of development and not mature enough nor cost effective enough for the majority of nanosatellite teams to implement, and cannot be required without inhibiting the growth of the nanosatellite community as a whole.

Mini-Cubes, LLC

www.mini-cubes.com

Since 2018, Mini-Cubes, LLC has been developing PocketQube satellites on a commercial basis. These pico-satellites are designed to monitor Earth Resources, primarily fresh water supplies as they change across our planet. We believe that by monitoring these supplies, we can make better choices that will extend the life of existing water resources as well as predict drought and flood conditions. Mini-Cube satellites are constructed using commercial off the shelf components as well as custom components.

Skyline Celestial

Skyline Celestial is a U.S. developer of commercial nanosatellite buses and integration platforms for low cost satellite applications.

Alba Orbital

www.albaorbital.com

Alba Orbital is the world’s leading PocketQube satellite manufacturer and launch broker. The company was founded in 2012 in Glasgow, Scotland and recently opened its second office in Berlin, Germany. To date, Alba launch has successfully deployed 6 PocketQube satellites into orbit including the Unicorn-2 platform. Unicorn-2 is the world's most capable Picosat by specification. Albaconnect, a ground station service developed by Alba, completes the full end-to-end service to newspace users and operators. Alba has 20+ customers on 3 continents.

Citadel Space Systems
www.citadel.space
Citadel Space Systems Ltd is a nanosatellite development company based in the United Kingdom and Spain. We design cubesat and pocketqube platforms in a variety of form factors, primarily focussed on providing for the science, research, and technology demonstration markets - flying in both Low Earth Orbit and deep-space environments. Our main product lines emphasise highly integrated, inexpensive, and rad-tolerant systems, enabling much longer-lived and more capable nanosatellite systems than have been flown previously. Due to the class of missions we provide for, we expect a significant proportion of our business to be American customers - we build high-performance science platforms that will enable U.S. research institutions to perform more science at lower cost. To provide that value to the American public, we are interested in promoting regulations that are safe and sustainable while being supportive of further development of the nascent nanosatellite field.

Fossa Systems
www.fossa.systems
Fossa Systems is an association based in Spain and dedicated to the development of picosatellite technologies and more specifically, PocketQubes. These small satellites reduce development times to months and can be launched into space for less than the cost of a car. Fossa Systems started the development of the first Spanish pocketqube spacecraft, FOSSASAT-1, in mid-2018. This open-source 1P satellite is experimenting with new spread spectrum LoRa technology for the internet of things and is a demonstrator for the new miniaturized architecture. Fossa Systems is carrying out several launches from U.S. soil and expects to carry out several contracts with American customers under FCC legislation. Fossa Systems is developing an IOT constellation and wishes not to hinder the access that the U.S. market could have to it.

Signatories

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Appendix A. Collisions Involving Megaconstellation Satellites Are Almost Certain Unless the Thresholds for Allowable Conjunction Probability of Collision is Unrealistically Low

We evaluate the aggregate probability of collision of a very large constellation resulting from various thresholds for the probability of collision considered allowable for a single conjunction (the "Conjunction Threshold"). As Starlink is the largest constellation currently on orbit, we use conjunction reports involving at least one of its satellites. We take the conjunction reports from Celestrak for the week of Monday, October 5, 2020 as a sampling of the quantity of conjunctions and their maximum probabilities of collision. We extrapolate these reports for the expected growth of the Starlink constellation from its current 680 to ~15,000. The resulting weekly quantity of megaconstellation conjunctions is given in Table 1.

Assuming these conjunction quantities are a representative sample of weekly conjunctions, we can extrapolate the aggregate 5-year-lifetime probability of a single collision being caused by the megaconstellation. This aggregate collision probability is given in Figure 1 versus various Conjunction Thresholds. We assume that all Starlink systems remain functional, such that all Starlink satellites involved in a conjunction with probability of collision above a given Conjunction Threshold are maneuvered until their probability of collision meets the Threshold. Figure 1 shows that maneuverability is ineffective at mitigating collision risk for megaconstellations, except for very low Conjunction Thresholds. For example, Figure 1 shows that using a Conjunction Threshold of 0.001, as recommended by Telesat, leads to near-certainty that at least one collision, if not more, will be caused by the megaconstellation. For megaconstellations, reducing the Conjunction Threshold by several orders of magnitude is still ineffective at reducing the aggregate probability of collision.

Table 1. Weekly Quantity of Megaconstellation Conjunctions by Risk Category. Weekly conjunctions involving at least one Starlink satellite are sorted by order of magnitude of probability of collision associated with the conjunction. Weekly conjunction quantities for the 680-satellite constellation are taken

from the < 5 km conjunctions list provided by Celestrak for the week of Monday, October 5, 2020. Extrapolated quantities are obtained by multiplying the weekly column by the expected Starlink constellation growth, roughly 15000/680 = 22. The final column shows the weekly, extrapolated, aggregate collision risk for the collection of conjunctions in that risk class.

Conjunction Probability of Collision	**Weekly Conjunction Quantity with 680 Satellites**	**Weekly Conjunction Quantity Extrapolated to 15,000 Satellites**	**Aggregate Weekly Probability of Collision for Extrapolated Conjuctions**
>0.001	1	*22*	2.18E-02
>0.0001	11	*243*	2.40E-02
>0.00001	>108	*2,382*	2.35E-02
>0.000001	No Data	*12,353*[3]	1.23E-02

Table 2. Intermediate Results in Aggregate Probability of Collision Calculations. For several Conjunction Thresholds that operators could select, the resulting 1-week and lifetime aggregate probability of collision are shown, accounting for both the conjunctions reduced to the threshold risk class and the conjunctions that are ignored at lower risk classes. The lifetime probability of collision is plotted as a function of Conjunction Threshold in Figure 1.

Conjunction Threshold	**1-week Aggregate Probability of Collision**	**Lifetime Aggregate Probability of Collision**
1.00E-03	8.16E-02	1.00E+00
1.00E-04	6.19E-02	1.00E+00
1.00E-05	3.84E-02	1.00E+00
1.00E-06	1.49E-02	9.80E-01
1.00E-07	1.50E-03	3.23E-01
1.00E-08	1.50E-04	3.82E-02
1.00E-09	1.50E-05	3.89E-03

[3] We assume that each satellite is involved in one and only one collision. This limits the 0.000001 probability of collision category to 12,353, instead of following the full 10X growth trends of the previous categories.

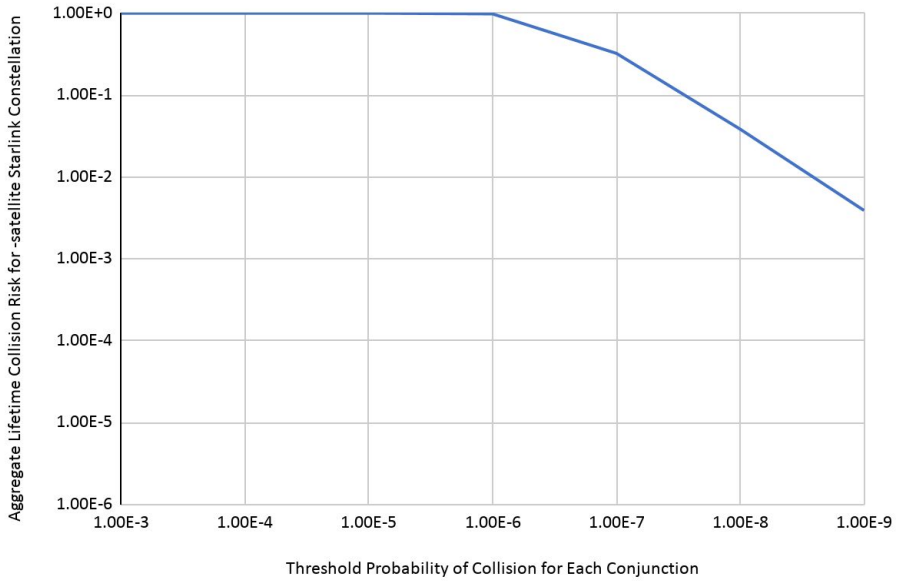

Figure 1. Lifetime Risk of a single Megaconstellation Collision by Allowable Conjunction Risk. Maneuverability is ineffective at reducing collision risk except at very low thresholds for allowable probability of collision for a single conjunction. This is due to the quantity of conjunctions shown in Table 1 increasing by an order of magnitude for each order of magnitude reduction in the allowable probability of collision for a single conjunction.

Appendix B. Maneuverable Megaconstellations Likely Present Orders of Magnitude More Debris Risk Than Non-maneuverable Small Constellations

For a representative example of a small constellation of non-maneuverable small satellites, we take the roughly 200-satellite Planet Flock constellation. For the week of Monday, October 5, 2020, Celestrak reported 19 conjunctions involving Flock satellites with probability of collision of 1.0E-6 or greater. The average probability of collision for these conjunctions was 6.78E-5. Neglecting possible conjunctions with lower orders of magnitude of risk, the lifetime aggregate probability of collision for the Planet Flock constellation is 0.0175. This assumes Planet's satellites have a lifetime of 5 years for comparability to the megaconstellation.

In Appendix A, we found that a 15,000-satellite megaconstellation that uses its maneuverability to achieve Conjunction Threshold of 1.0E-6 will almost certainly have a collision (probability 0.98). The maneuverable megaconstellation has 0.98/0.017 = 58X greater chance of collision than the non-maneuverable small, nanosatellite constellation. This is highly conservative, as it assumes only one satellite in the megaconstellation is involved in a collision and that no satellites in the megaconstellation fail making them unable to bring their risk down to threshold! The megaconstellation collision is not only more likely, but almost certainly produces significantly more debris, as its satellites are 260kg/4kg = 65X more massive. When accounting for the allowable threshold of probability of collision for a single conjunction, maneuverability is ineffective as a measure of debris risk!